



1985 NASA-ROCKWELL SPACE STATION CREW SAFETY STUDY: RESULTS FROM MIR

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Dedicated to

- Dr. Trieve A. Tanner
- First Chief, 1983-85
- Ames Space Human Factors Office
- Mentor for the Space Station Human Factors—Crew Safety Interaction Model

Timeline of the Story

- 1971 Salyut 1 Space Station--crew of 2 dies in reentry
- 1973 Skylab Space Station
- 1982-85 Salyut 7 Space Station--Cosmonaut arrhythmia.
- 1984 Ames Space Station Human Factors— Crew Safety Interaction Model
- 1984-85 Rockwell Crew Safety Interaction Model Study -- Ames COTR for Vol. 3 HUMAN FACTORS.
- 1986 Loss of Challenger w/7 crew
- **1986 Launch of Mir**
- 1999 Launch of ISS Functional Base Block 1
- **2000 De-orbit of Mir**
- 2002 Loss of Columbia w/7 crew
- 2003 Presentation of *Results from Mir* to IBMP 40th Anniversary Conference in Moscow

Mir Service Life: 14 Years

- Mir was launched in 1986, with a planned service life of 5 years.
- The demise of the Soviet Union prevented the planned launch of Mir 2 in 1991.
- The Russians “Made do” with the Mir Cluster for almost 3X longer than the design lifetime.
- Serious, life-threatening problems arose in the last four years, coinciding with the US/Russian Shuttle-Mir collaboration.

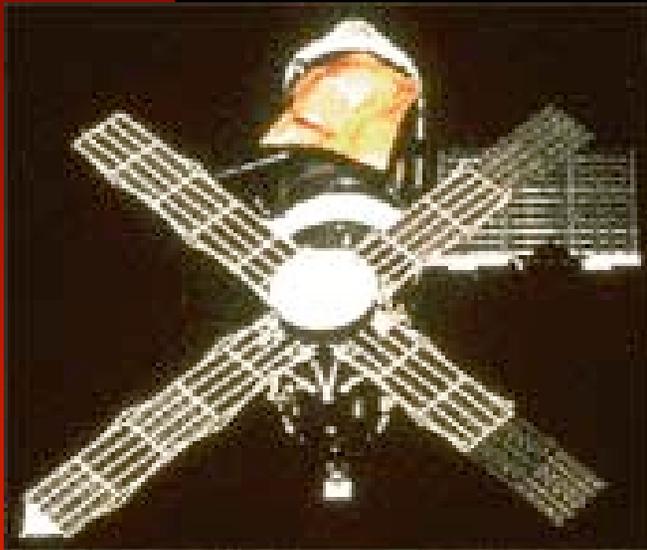
Early Safety Hazards and Threats in NASA Human Space Program

- Gus Grissom's Mercury Capsule sinks--question of error.
- Apollo 1 Pad Fire kills Grisson, White & Chafee.
- Apollo 13 Electrical Explosion aborts mission.
- Skylab 1 Launch - Heat Shield Torn Off.
- Skylab 4 Crew "Strike" 1 day because of overwork.
- STS-2 Toluene cement for velcro exceeds SMAC.
- STS-5 "Ace Trucking Company" sign made with toxic marker from uninspected astronaut personal kit.
- STS-9: Rockwell Crew Safety refuses to sign off on Spacelab 1 Life Support, Spacelab hatch seizes up.
- Lockheed Electropherisis Unit in Spacelab appears to ignite, crew does emergency shutdown.



Skylab Experience 1973

- Heat Shield Tore Off On Launch
- Two Missions to Provide Replacement Shield



Skylab 2 Parashute Deployed
Through the Science Airlock

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Skylab 3 Folding Shade
Deployed by EVA



Figure A: Space Station Crew Safety— Human Factors Interaction Model (Cohen and Junge, 1984)





Figure 1. Protocols

STRESSORS	 COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	 COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
Scheduling Overload	Scheduling Changes; Crew Rotation	Scheduling Conflict	Daily Scheduling; Staff Meetings	Lack of Coordination; Misunderstanding
Family Problems	Family Interaction; Secure Communications	Abnormal Behavior; Depression	Discipline; Counseling	Deliberate Conflict; Inability to Work
Disagreements with Ground Control	Autonomy from Ground	Conflicting Objectives	Changes in Mission Objectives	Violation of Safety Criterion
Territoriality	Access/Non-access	Turf Conflicts	Negotiations	Improper Entry or Inadequate Access
Incompatibilities	Crew Selection; Crew Training	Incompatibilities	Training; Group Process	Lack of Cooperation



Figure 2.a. Critical Habitability I

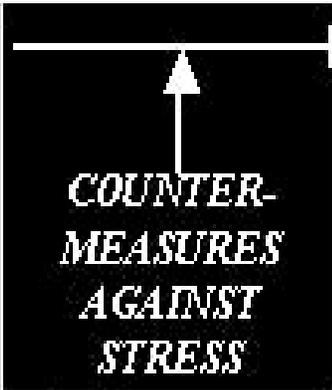
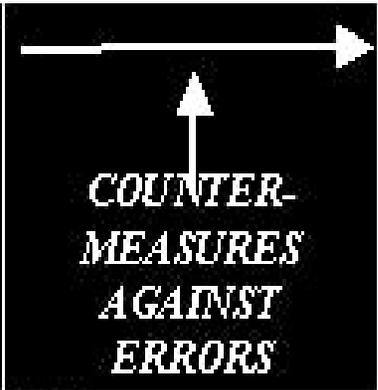
STRESSORS	 <i>COUNTER-MEASURES AGAINST STRESS</i>	DEGRADED PERFORMANCE	 <i>COUNTER-MEASURES AGAINST ERRORS</i>	SAFETY HAZARD
Volume Limitations	Architecture: Design Privacy, Windows	Feelings of Claustrophobia; Lack of Privacy	Privacy or Evacuation	Irritability; Paranoia
Noise	Vibration Isolation and Control	Sleep Disturbances; Poor Communication	Earmuffs; Headsets; Drugs; Communication Devices	Failure to Respond; Failure to Communicate or Coordinate
Housekeeping (or Lack Of)	Routines and Training	Environment Quality; Deterioration	Assignment of Responsibilities; Teamwork	Breakdown in Life Support
Hygiene; Cleanliness	Personal Practices; Training	Discomfort to Others; Illness; Disease	Group Standards	Personal Illness; Inability to Perform Tasks



Figure 2.b. Critical Habitability II

STRESSORS	 COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	 COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
Thermal/Humidity; Closed Atmosphere	Environmental Controls	Discomfort; Irritability	Air Movement; Gas Composition and Control; Temperature and Humidity Control	Increased Anxiety
Confinement, Isolation, Separation	Communication with Family and Friends; Visitors; Social Events; Recreation; Counseling; Architecture Geometry; Stowage	Loneliness; Morale Deterioration; Impaired Judgment; Perception Under Stress; Claustrophobia	Group Activities; Hobbies; Personal Interests; Judgment Checks; Color Coding; Lighting; Multiple Access, Mobility Aids	Breakdown in Group Process; Teamwork; Mistakes in Judgment, Perception, or Action; Paranoia
Artificial Lighting	Lighting Design; "Natural Light"	Fatigue, Irritability, Blurred Vision	Special Task Lighting	Mistaken Perception



**Figure 3. Task Related Issues:
TASK ASSIGNMENT/ROLE DEFINITION**

STRESSORS	 COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	 COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
Work Environment Problems	Station Organization/Design	Fatigue Factors	Work Station Design	Mistake/Inadvertent Action
Work Organization Leadership	Leadership Training; Consensus	Conflicts with Leadership	Crisis Resolution; Chain of Command	Conflicting Actions
Task Assignment	Task Selection	Monotony; Boredom	Task Rotation	"Familiarity Breeds Contempt"; Lack of Caution
Physical Limitations	Crew Selection; Physical Endurance	Strain on Endurance	Mandatory Physical Exercise Regimen	"Cutting Corners"; Physical Inability to Perform Tasks
Scheduling and Coordination Conflicts	Group Activities and Meetings	Low Morale and Motivation	Crew/Buddy Checks and Drills	Lack of Effective Crew Interaction



Figure 4. Crew Incapacitation

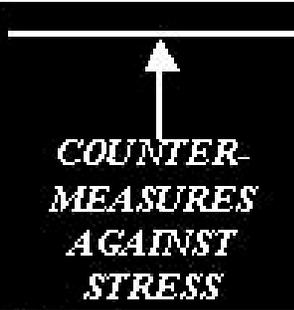
STRESSORS	 <i>COUNTER-MEASURES AGAINST STRESS</i>	DEGRADED PERFORMANCE	 <i>COUNTER-MEASURES AGAINST ERRORS</i>	SAFETY HAZARD
Space Sickness; Gas Bubbles in Water	Selection; Adjustment; Maintain/Check Water System	Poor Task Performance; Gas Pains	Treatment; Improve Water System	Crew Failures to Respond
Illness	Examinations and Health Maintenance Program	Short Term Incapacitation	Treatment	Contagion?
Injury	Space Industrial Safety	Long Term Incapacitation	Return to Earth? Stabilize on Orbit?	Distraction of Other Crew Members
Emotional/Mental Problem	Crew Selection and Training	Lack of Trust and Cooperation	Relief from Duty	Abnormal Behavior; Detrimental Actions
Failure in Life Support System	Abandon, Evacuate One Module	Confinement, Trauma	Repairs, Replacement	Loss of Access to Critical Functions
Death of Crew, Family or Friend	Counseling	Trauma to Crew; Disruption of Teamwork	Counseling	Preservation or Disposal of Body; Inability to Work



Figure 5. Personal Choice

STRESSORS	 COUNTER-MEASURES AGAINST STRESS	 DEGRADED PERFORMANCE	 COUNTER-MEASURES AGAINST ERRORS	 SAFETY HAZARD
Cooking/Eating Habits (Restrictions)	Shared Meals; Accommodation for Individual Crew Preference	Irritation, Depression	Adequate Training	Fire, Odors, Outgassing
Individual Property (Restrictions)	Education; Monitoring and Control; Crew Training	Personal Autonomy Diminished; Low Morale	Monitoring and Control	Outgassing, Contamination, Flammability
Boredom, Monotony	Entertainment; Crew-selected Activities	Lack of Vigilance	Adequate Crew Activities; Planning and Scheduling	Practical Jokes, Distraction, Accidents
Clothing	Variety, Laundry, Crew Preference	Irritation, Discomfort, Less Personal Freedom	Clean Filters	Lint Problem, Contamination, Fire
Personal Habits: Alcohol, Drugs	Crew Selection, Crew Training	Effects of Overuse; Withdrawal Symptoms	Counseling; Evacuation	Fire; Impaired Judgement



The 1985 NASA-Rockwell International Study identified these key safety threats:

Rockwell Study Team:

- Robert Peercy
- Robert Raasch
- Lisa Rockoff
- George Mead
- Robert Witcofski, LaRC, COTR, Vols. 1,2, 4, 5
- Marc Cohen, ARC, COTR, Vol. 3 "Safety Impact of Human Factors"

- Fire
- Explosion
- Collision/Out of Control, Tumbling
- Decompression
- Contamination
- Radiation
- Human Error

Space Station Modules Launched to LEO

Laboratory Name	Origin	Date	Length m	Dia. m	Mass Kg.	Pressurized Volume m ³	Key Payloads	Remarks
Skylab Orbital Workshop	USA	1973	14.7	6.5	35,400	336	Life Science, Biomedical, Earth Observations	Derived from Saturn upper stage
Salyut-6	USSR	1976	13.1	2.0 - 4.15	19,825	~80	Life Science, Space Science	Earlier Salyuts similar
Salyut-7	USSR	1982	13.1	2.0- 4.15	19,825	~80	Life Science Space Science	
Mir Core	USSR	1986	13.13	4.15	20,900	90 380 total Mir Cluster	habitation, power, life support, sleep stations, toilet	Added Radial docking ports to Salyut design
Mir-Kvant-1	USSR	1987	5.8	4.15	11,050	30	Astrophysics	
Mir-Kvant-2	USSR	1989	13.7	4.15	18,500	61.9	Logistics, EVA airlocks, toilet	
Mir-Kristall	USSR	1990	11.9	4.35	19,640	60.8	Materials Processing	
Mir-Spektr	Russia	1995	9.1	4.35	19,640	~60	Geophysical Science	Refurbished to receive US payloads on orbit
Mir-Priroda "Nature"	Russia	1996	9.7	4.35	19,700	~60	Remote Sensing, Earth Science, Oceanography	Designed to incorporate US research

FIG 7. Salyut-6 Configuration with Soyuz vehicle berthed to it, 1977, courtesy of RKK Energia.

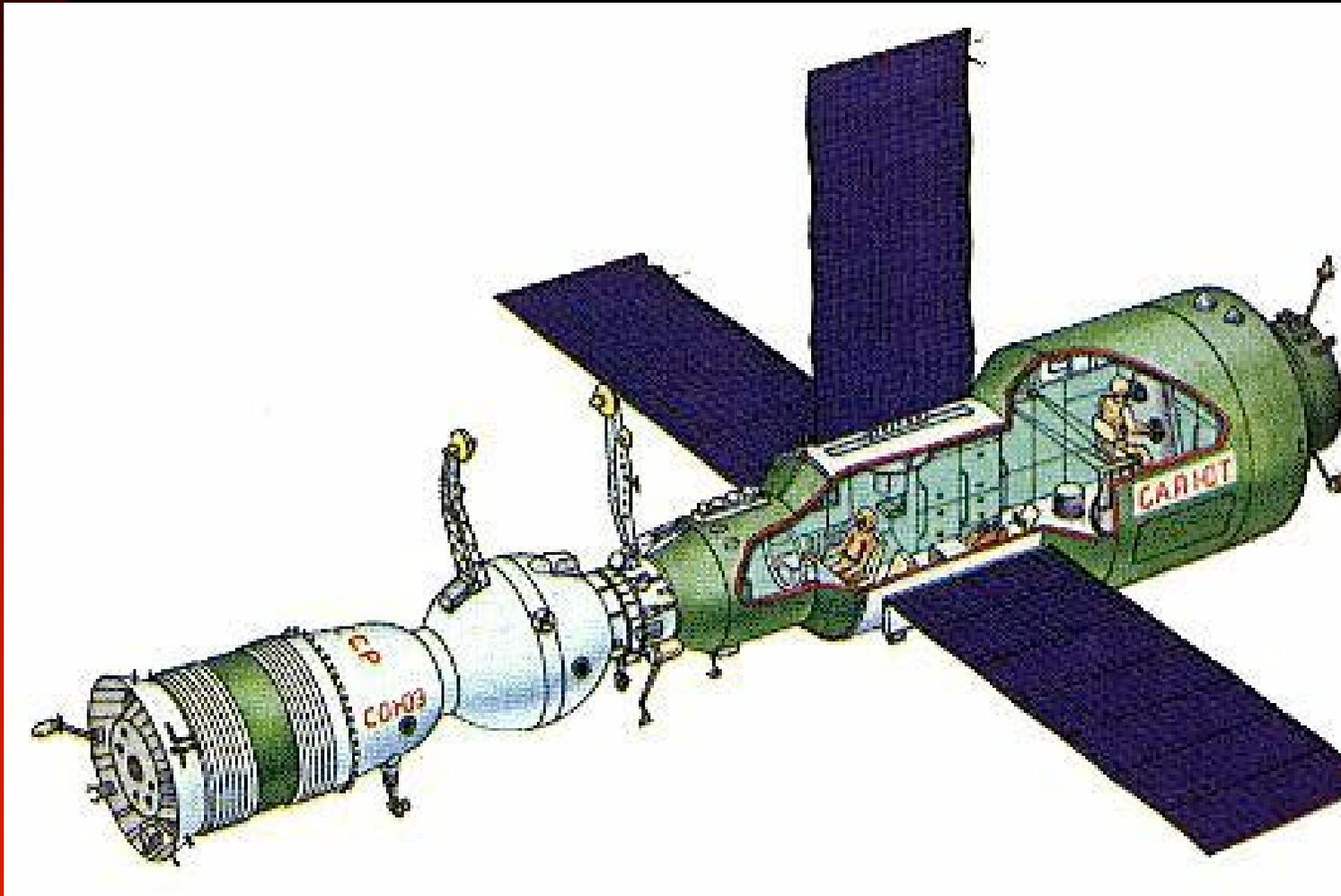


FIGURE 8. Mir core under preparation for launch at Biakonur Cosmodrome. Courtesy RKK Energia.



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17

FIG. 9 Shuttle-Mir

- 1) U.S. Space Shuttle
- 2) Docking tunnel
- 3) Kristall module: materials processing, exercise treadmill,
- 4) Kvant-2 module: logistics, EVAirlock toilet
- 5) Soyuz-T transport vehicle, docked at multi-port node
- 6) Spektr module: geophysical sciences, US experiments
- 7) Priroda module: U.S. facilities, Earth observation,
- 8) Core module: habitation, power, and life support
- 9) Kvant-1 module: astrophysics, docking port
- 10) Progress robot freight vehicle docked at Kvant-1 port

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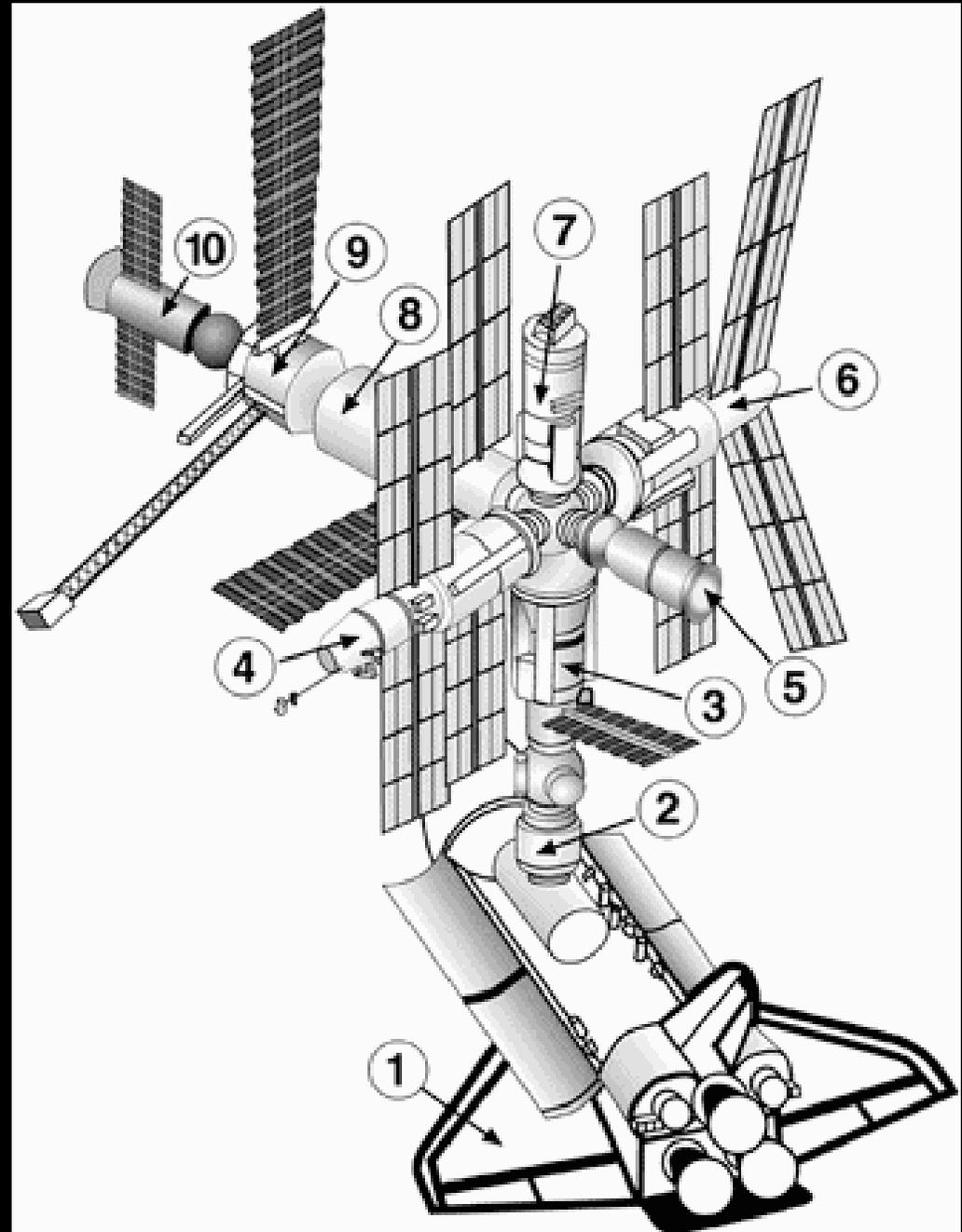


FIGURE 10. Kvant-1 Section Elevation line drawing, courtesy
Gagarin Cosmonaut Training Center (TsPK).

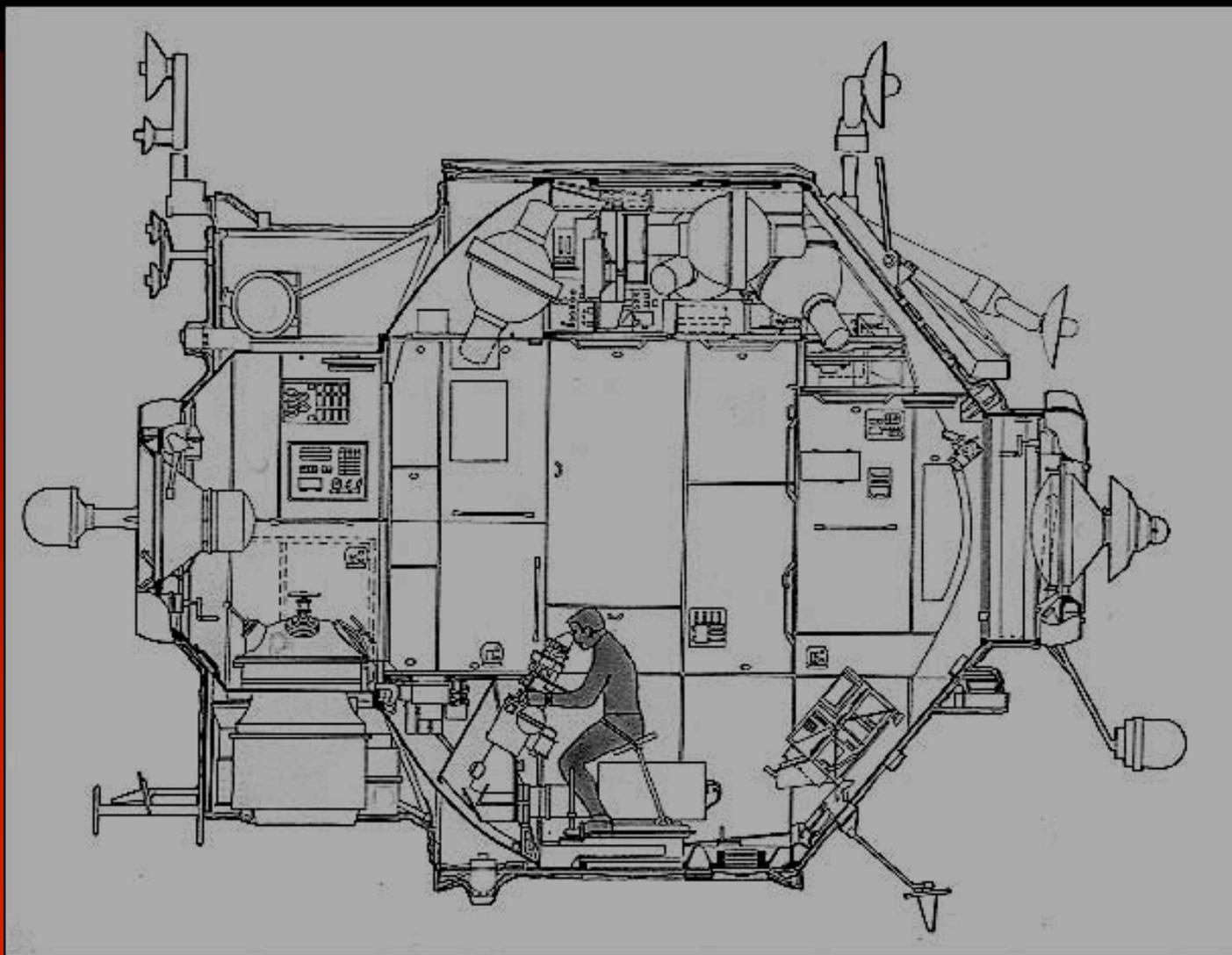


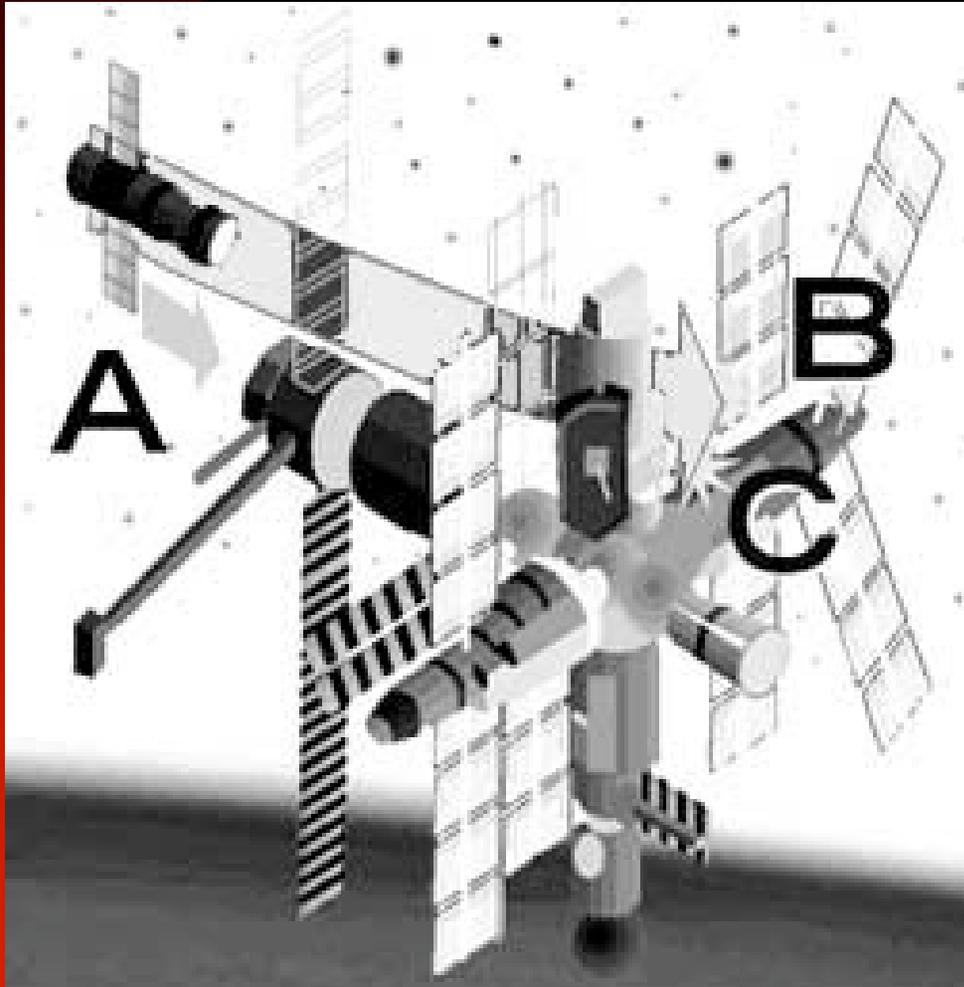
FIGURE 11. View of the Kvant-2 laboratory interior, credit NASA, photo taken by a US Shuttle-Mir astronaut.



FIGURE 12. Astronaut Shannon Lucid on Mir, with a materials science glovebox, most likely in the Priroda Laboratory module, courtesy of NASA Headquarters.

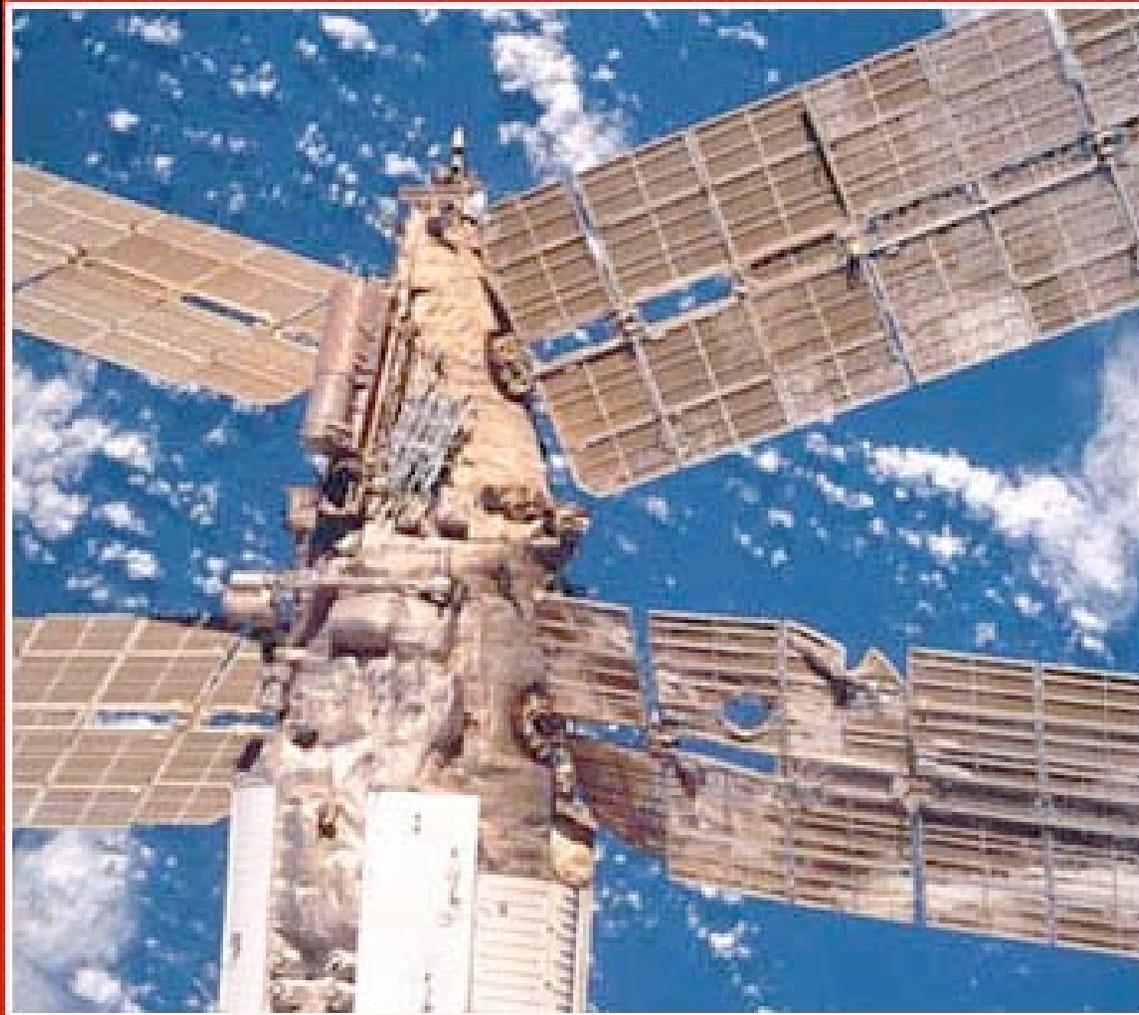


Progress Collision with the Spektr Lab Module on Mir, 1997



- FIGURE 13. Arrow shows the approximate collision path of Progress 234, A, striking the Spektr Module's solar panels at B and Spektr itself at C, (courtesy of Stephen Ellis, NASA-Ames).
- *Had Tsibliev, Lazutkin, and Foale not been able to seal off the decompressed module fast enough following the collision they might have died.*

FIGURE 14. Damaged solar panels on the Mir Spektr Laboratory Module, following the collision by an unmanned, Progress cargo vehicle in 1997 during a robotic docking maneuver, Courtesy of NASA-Johnson Space Center.



Threat Concerns in **Bold** apply to the Progress collision with the Spektr module on Mir in 1997.

Threat Concerns in *Italics* apply to the fire and coolant leak on Mir.

Threat Concerns in **ALL CAPS** apply both to the collision and the other incidents on Mir.

General Threats to Safety (Volume II)	Safety Impact of Human Factors (Volume III)	Space Station Safety Plan (Volume V)
<i>Fire</i>	CRISIS MANAGEMENT	Leakage
Biological and <i>Toxicological Contamination</i>	Confinement/ Isolation	Tumbling/Loss of Control
INJURY/ILLNESS	Acoustics and Noise	Grazing/Collision
Explosion/Implosion	Territorial Issues	Corrosion
Loss of Pressurization	BEHAVIORAL PROTOCOLS— FATIGUE	Mechanical Damage
Radiation	<i>Scheduling</i>	Out of Control IVA/EVA Astronaut
Meteoroid Penetration	<i>Cleaning/Disinfecting</i>	Inadvertent Operations
Space Debris impact	Hygiene	LACK OF CREW COORDINATION
	VIOLATION OF SAFETY	

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11/4/04	VIOLATION OF SAFETY	25



How robustly predictive would the Cohen and Junge model be?

Methodology:

Comparison of the model with the 7 *Mir-NASA* missions.



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